# Interannual Variability in Isotope-Climate Relations in the Canadian Arctic

S. Jean Birks[1], Thomas W.D. Edwards[1], Fred A. Michel[2], and John J. Gibson[3]

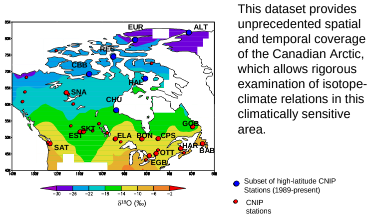
[1]Department of Earth Sciences, University of Waterloo, Waterloo, Canada
[2]Department of Earth Sciences, Carleton University, Ottawa, Canada
[3]Water and Climate Impacts Research Centre, Environment Canada, Victoria, Canada

For more information contact: sjbirks@sciborg.uwaterloo.ca

http://www.science.uwaterloo.ca/~twdedwar/cnip/cniphome.html

### Introduction

The distribution of stable isotopes in precipitation provides fundamental information about the partitioning of the global atmospheric water budget, and hence about key aspects of Earth's climate, that cannot be discerned using other means. Although continuing demand exists for monitoring of isotopes in precipitation to define isotopic input functions for local hydrologic studies or for calibration of isotopic indicators of paleoclimate, awareness is also growing of the significant value of "snapshots" of the precipitation isotope fields as benchmark maps of the ongoing and dynamic evolution of the global water cycle. The Canadian Network for Isotopes in Precipitation (CNIP) includes a 14-year dataset of composite monthly stable isotope measurements from six stations located in the Canadian high-latitudes.




This dataset provides unprecedented spatial and temporal coverage of the Canadian Arctic, which allows rigorous examination of isotope-climate relations in this climatically sensitive area.

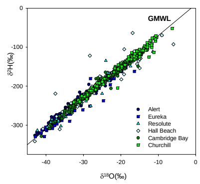
### Background: Isotope-Climate Relations

The strong correlation between the stable isotope ratios of oxygen and hydrogen of precipitation and mean annual temperature observed in high latitudes is the basis for the traditional interpretation of stable isotope content of paleoprecipitation archives in terms of paleotemperatures.

However, precipitation isotope fields, including *d*-excess, are integrated climate parameters that reflect vapour source and history as well as temperature and amount effects.

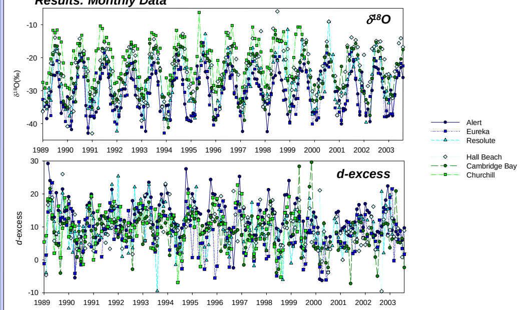
### Data

Here we present the results of the first 14 years of monitoring from our six high-latitude stations. Monthly composite precipitation samples were analyzed for $\delta^{18}O$ and $\delta^{2}H$.




The data are clustered about the Global Meteoric Water Line.

### Results: Monthly Data




The annual cycle of more depleted $\delta^{18}O$ values in the winter, and more enriched $\delta^{18}O$ values in the summer is clearly visible.

A general trend of higher *d*-excess values in the winter and lower values in the summer is likely due to kinetic effects during snow formation and post-condensation evaporative enrichment.

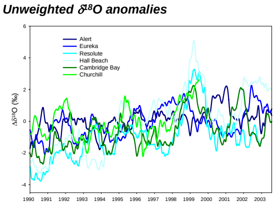
In addition to the annual signals in both parameters, interannual trends are also apparent.

### Isotope Anomaly Time-Series

Isotope anomalies were calculated by performing 12-month moving averages (unweighted and weighted using precipitation amount) to remove the seasonal signal.

Despite the large region represented by these six stations, time-series of isotope anomalies show some spatially coherent trends, but also include periods when there are regional differences in the direction, timing and magnitude of the anomalies.

#### Unweighted $\delta^{18}O$ anomalies

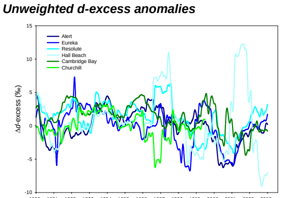



The $\delta^{18}O$ anomaly time-series from Resolute, Hall Beach, Cambridge Bay and Churchill are fairly well correlated. Notable in this time-series is the positive $\Delta\delta^{18}O$ ending around 1999, possibly related to El Niño.

Correlation coefficients (r) between the unweighted $\delta^{18}O$ anomaly time-series from each of the stations.

| | Alert | Eureka | Resolute | Hall Beach | Cam.Bay | Churchill |
|---|---|---|---|---|---|---|
| Alert | 1.00 | | | | | |
| Eureka | 0.32 | 1.00 | | | | |
| Resolute | 0.14 | 0.48 | 1.00 | | | |
| Hall Beach | 0.42 | 0.53 | 0.78 | 1.00 | | |
| Cambridge Bay | -0.01 | 0.41 | 0.89 | 0.71 | 1.00 | |
| Churchill | 0.06 | 0.42 | 0.61 | 0.60 | 0.63 | 1.00 |

#### Unweighted d-excess anomalies




The *d*-excess anomaly time-series also show some spatial and temporal coherence.

### Isotope Anomaly Time-Series: Unweighted vs. Weighted

Unweighted and amount-weighted isotope anomaly time-series were compared with temperature and precipitation anomalies as well as with the AO, NAO and PDO.

• The unweighted and weighted isotope-climate relations provide us with different types of information.

#### Unweighted

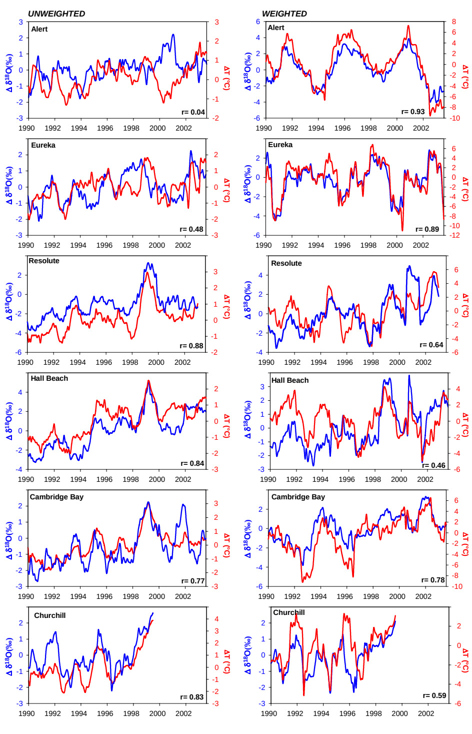
| Correlations | Alert | Eureka | Resolute | Hall Beach | Cambridge Bay | Churchill |
|---|---|---|---|---|---|---|
| $\Delta\delta^{18}O$ ΔT | 0.04 | 0.48 | 0.88 | 0.84 | 0.77 | 0.83 |
| Δ*d*-excess ΔT | 0.24 | 0.08 | -0.37 | -0.04 | -0.20 | -0.08 |
| $\Delta\delta^{18}O$ AO | -0.25 | -0.49 | -0.47 | -0.44 | -0.40 | -0.22 |
| $\Delta\delta^{18}O$ NAO | -0.26 | -0.58 | -0.48 | -0.63 | -0.48 | -0.33 |
| $\Delta\delta^{18}O$ PDO | -0.25 | 0.19 | -0.13 | -0.21 | -0.19 | -0.36 |

The relations between **unweighted** isotope signals and climate parameters in precipitation provides information on how changes in hydroclimatology are expressed isotopically, particularly at a regional scale.

#### Weighted

| Correlations | Alert | Eureka | Resolute | Hall Beach | Cambridge Bay | Churchill |
|---|---|---|---|---|---|---|
| $\Delta\delta^{18}O$ ΔT | 0.93 | 0.89 | 0.64 | 0.46 | 0.78 | 0.59 |
| Δ*d*-excess ΔT | -0.45 | 0.01 | -0.14 | -0.56 | -0.49 | 0.07 |
| $\Delta\delta^{18}O$ AO | -0.20 | -0.17 | -0.28 | -0.23 | -0.24 | -0.20 |
| $\Delta\delta^{18}O$ NAO | -0.09 | -0.19 | -0.33 | -0.39 | -0.37 | -0.31 |
| $\Delta\delta^{18}O$ PDO | -0.33 | 0.36 | -0.39 | -0.33 | -0.21 | -0.20 |

Paleoprecipitation archives (e.g. ice cores) retain a **weighted** isotope signal, so understanding the relation between weighted isotope anomalies and climate parameters is also critical.



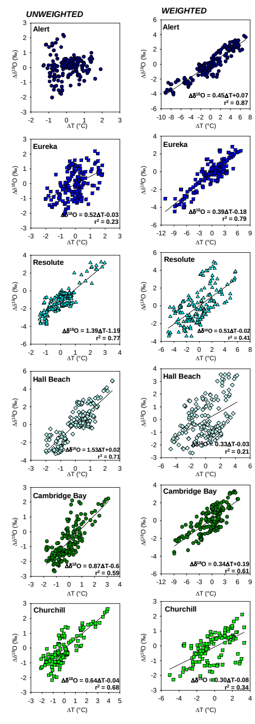

• Amount-**weighted** isotope anomaly time-series from Alert and Eureka are strongly correlated with weighted temperature anomalies.

• In contrast, **unweighted** $\delta^{18}O$ and T anomalies at these two stations show almost no (Alert) to weak (Eureka) correlations.

• Unlike the two most northerly stations, the **unweighted** isotope and temperature anomalies at the remaining stations (Resolute, Hall Beach, Cambridge Bay and Churchill) are well correlated, suggesting that the seasonality of precipitation is not as important at these sites.

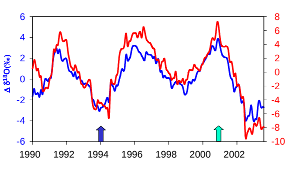
• The slopes of the **unweighted** $\Delta\delta^{18}O$-ΔT relation for these 4 stations are unusually high.

• The Cambridge Bay **weighted** isotope anomaly time-series displays opposite trends to the Alert record, suggesting differences in isotope-climate relations between these two regions.




### Alert: The Importance of Seasonality

The Alert weighted isotope anomaly time-series is particularly intriguing because of an extremely regular *ca* 6-year cycle between depleted and enriched weighted $\delta^{18}O$ anomalies.

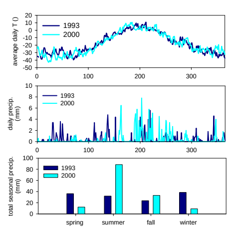



#### 1993 vs. 2000

Comparing two contrasting years gives insight into the origin of this cycle. Even though 1993 and 2000 had almost identical mean temperatures and total precipitation amounts, the weighted annual $\delta^{18}O$ averages were very different.

#### Alert: 1993 vs. 2000

| | Annual precip.(mm) | Weighted annual $\delta^{18}O$ (‰) | Mean annual temp. (°C) | NAO | PDO |
|---|---|---|---|---|---|
| 1993 | 130.8 | -31.0 | -17.6 | 0.42 | 1.42 |
| 2000 | 143.2 | -24.8 | -17.9 | 0.12 | -0.6 |




The key difference between the two years appears to be the seasonality of precipitation.

1993 was anomalous in that precipitation was distributed almost evenly throughout the year. It was a year of unusually strong winter cyclone activity in the arctic.

The distribution of precipitation in 2000 more closely resembled the typical annual pattern at Alert, with most of the precipitation occurring during the late summer and early fall. However, the amount of precipitation received during this summer, particularly the amount of rain, was unusually high.

The *ca* 6-year cycle present in the $\delta^{18}O$ time-series is not an indicator of a temperature anomaly cycle, but rather an indicator of systematic changes in the seasonality of precipitation at this site.

### Conclusions

• Spatially and temporally coherent isotope signals are evident in the data from the Canadian Arctic stations.

• The data show two general groupings of stations:
  • Alert and Eureka have weighted isotope anomalies that are strongly correlated with weighted temperature anomalies, suggesting that in this region isotope anomalies are related to changes in the seasonality of precipitation.
  • At Resolute, Hall Beach, Cambridge Bay and Churchill the unweighted isotope anomalies are strongly correlated with unweighted temperature anomalies.

• The causes of the regional isotope anomalies are not yet clear, however, their timing and regularity suggest that they may be related to changes in the water budget that accompany changes in atmospheric and oceanic circulation.

### Acknowledgements

• NSERC
• Meteorological Service of Canada
• Environmental Isotope Laboratory, University of Waterloo

Environment Canada Environnement Canada